
Radiation Tests of High-Density Memories

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Dynamic Memories

- Very high storage density
- Used in solid-state recorders
- Extremely sensitive to single-event upset
 - Requires error-detection and correction
 - Complex architecture of new DRAM types

Static Random Access Memories

- Lower storage density than DRAMs (four or six transistors per cell)
- Also very sensitive to single-event upset

Non-Volatile Memories

- Flash memories
- New NV technologies: FE memories
- Basic storage elements are immune to upset

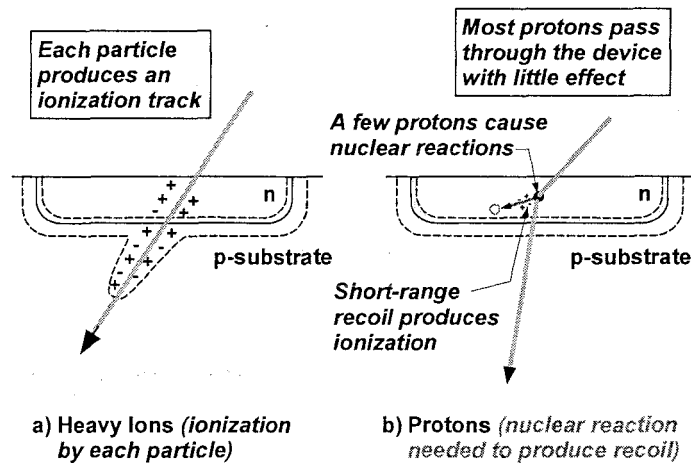
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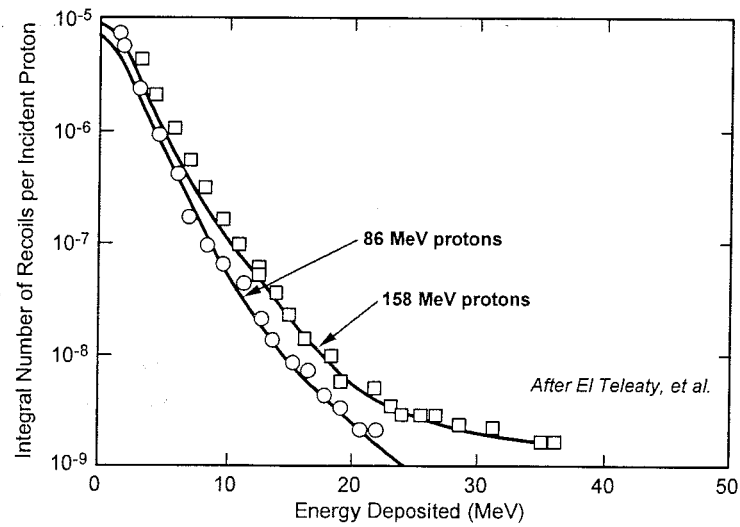
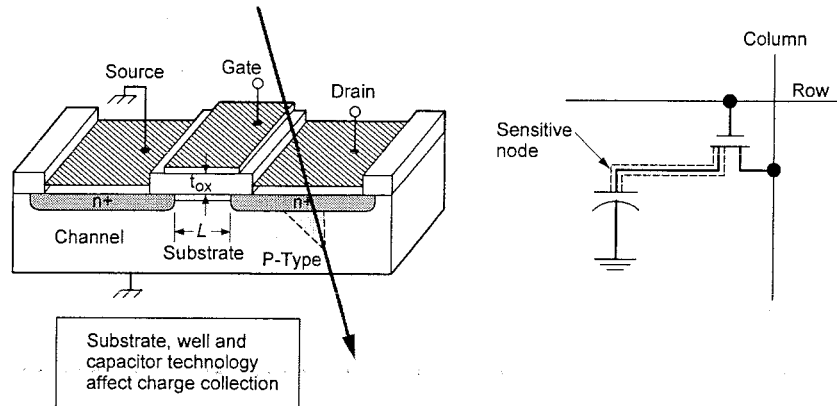
Heavy Ions

- Highly energetic particles
- Deposit charge up to 30 times greater than proton recoils in silicon
- Major issue for earth-orbiting spacecraft with inclination above 40 degrees
- Basic unit: linear energy transfer (LET) in MeV-cm²/mg

Protons

- Produce single-event effects as well as total dose
- South Atlantic anomaly exposes low-inclination spacecraft to protons
- Total proton fluence (after usually shielding assumptions) is typically between 10¹⁰ and 10¹¹ protons/cm²





High-Energy Protons Penetrate Package

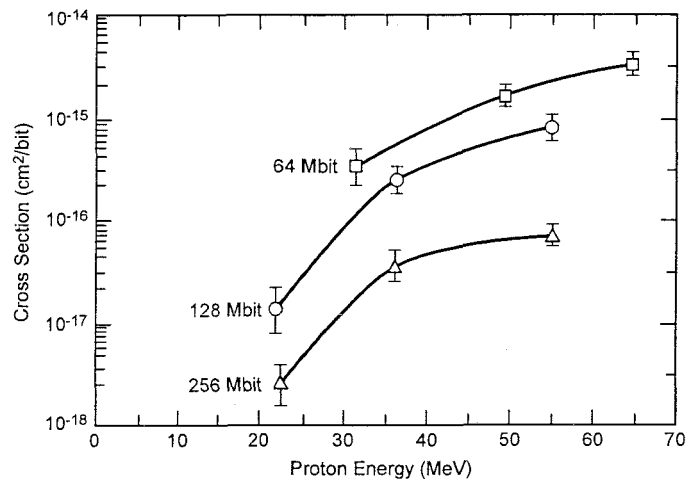
- Testing can be done in air with high-energy protons
- Low energy proton test results are also needed to calculate upset rate

Relatively High Fluences Are Required

- Some types of upsets have low cross sections compared to memory array
- May cause total dose or displacement damage that interferes with measurements

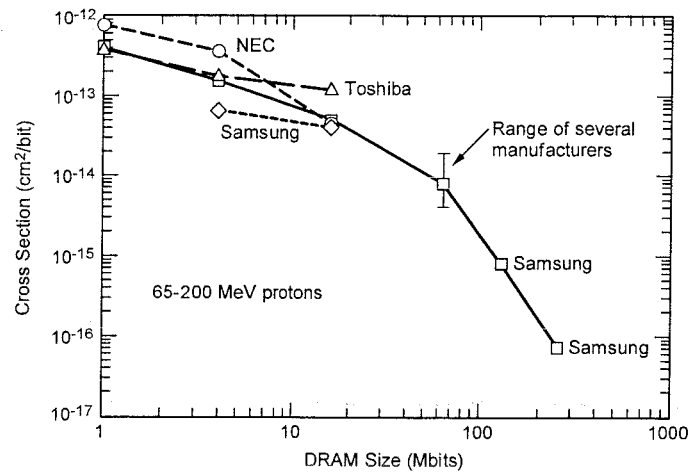
Proton Testing Produces Lower Internal Charge than Heavy Particles

- Equivalent to heavy ions with LET between 3 and 12 MeV-cm²/mg
- Some important effects don't necessarily occur with proton tests
 - Latchup
 - Multiple-bit upset

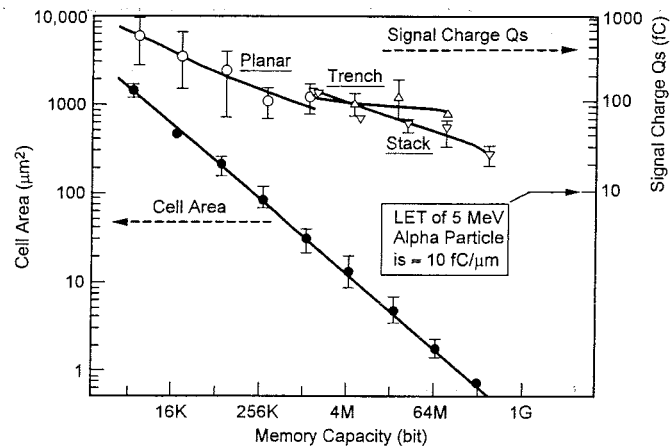


The energy dependence of proton upset does not change significantly for scaled devices at the 256-Mb level

Effects of Scaling on Proton Cross Section at High Energy



Cell Size and Storage Capacitor Trends for DRAMs



After K. Itoh, et al., Proc. IEEE, 1995

Difficult and Expensive

- Accelerator and engineering time ~ \$1000 per hour
- Testing must be done *in situ*
 - Most facilities require tests in vacuum
 - Device lids must be removed
 - Lead frames of modern DRAMs requires repackaging or irradiation from back

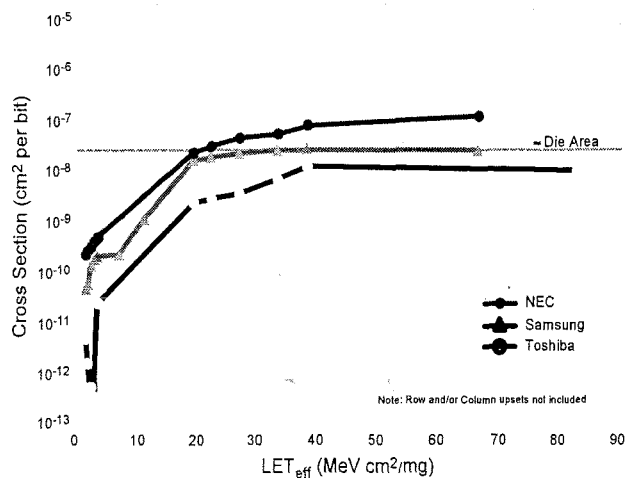
Ions Must Have Sufficient Range to Deposit Charge in Active Region

- Ions with short range will underestimate upset effects
- Range should exceed 40 microns for most device types

Interferences

- Total dose damage also occurs during irradiation with heavy ions
- Very complex test setups may be required for some parts
- Latchup

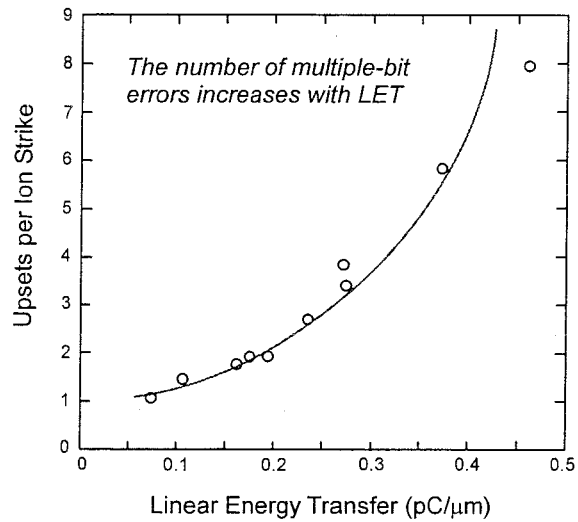
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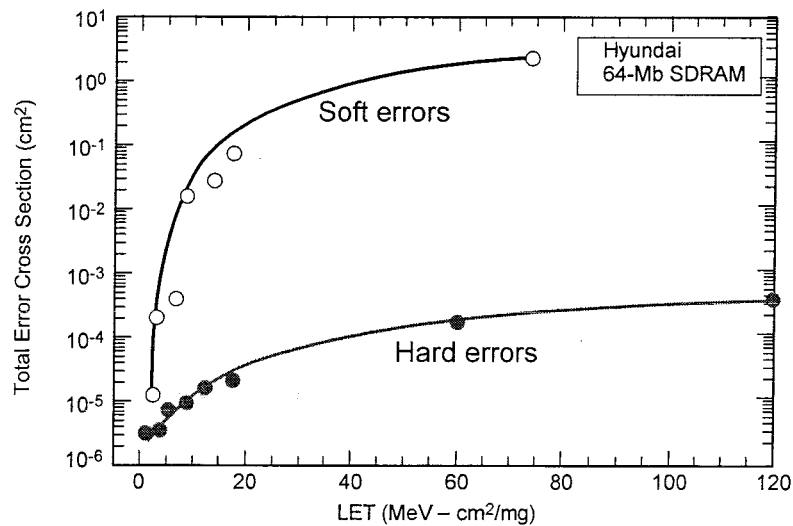
The upset cross section at high LET exceeds the die area because of multiple-bit upset

Multiple-bit error probability increases at high LET

Data shows mean number of upsets, but up to 60 upsets can be observed for some events



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Cells Do Not Upset

Very Complex Architecture Results in Functional Interrupts

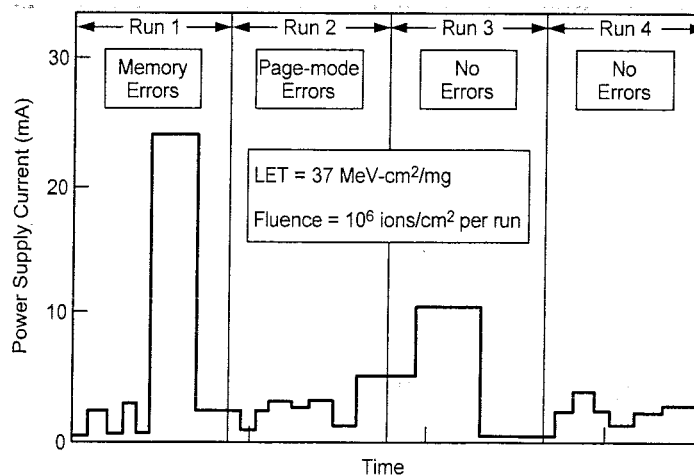
Creative Use of Flash Memories Can Mitigate These Effects

- Use devices in “mainly unpowered” mode
- Apply power just before use
- Avoid frequent erasing and writing

SEE Tests Are Usually Done in READ Mode

- Run for fixed interval
- Evaluate memory status after run
- Monitor status bits during run

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Issues

- Bias conditions during testing (including pattern storage)
- Test parameters
- Annealing of damage after irradiation

Typical Test Approach

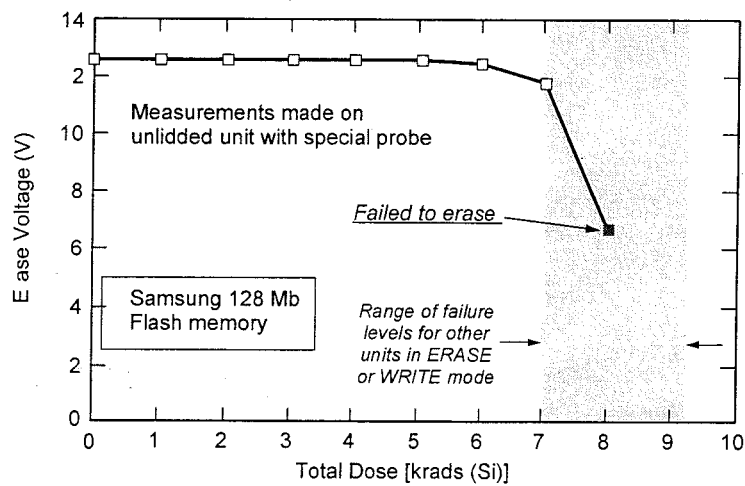
- Cobalt-60 gamma rays used for testing
- Apply bias, including pattern and memory functional state
- Perform electrical tests after each irradiation step

Usually includes measurements of retention time

Difficult to measure without special test equipment

Strongly affected by temperature ("use" temperature $\sim 70^\circ\text{C}$)

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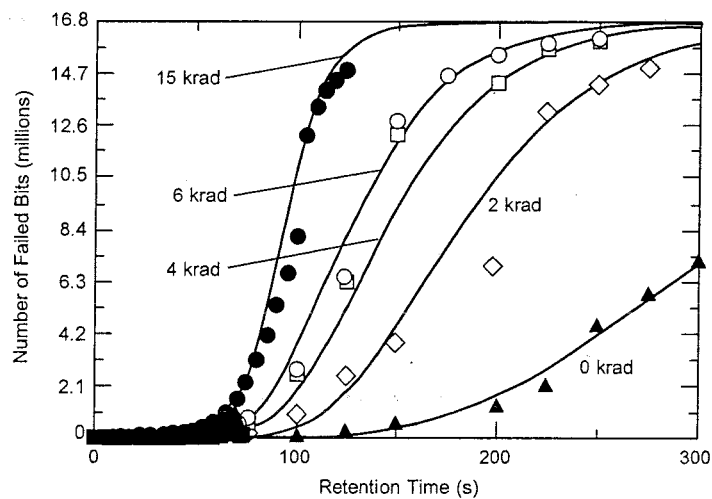
Charge Pump

- Internal charge pump voltage decreases
- Increases write time, eventually making device inoperative
- Typical failure levels: 6-7 krad(Si); 20 krad(Si) without bias applied

Field Oxide

- Large increase in overall power supply current
- Failure level varies widely for different devices

Sense Amplifier (Multi-Level Flash)



Memories Are Critical Components for Space Systems

- Cost, limited size of hardened memories limits their use
- State-of-the-art commercial memories are usually needed
- Memory technologies evolve rapidly

DRAMs Are Widely Used Despite Extreme Radiation Sensitivity

- EDAC allows single-event error mitigation
- Functional errors and latchup are important for newer devices
- Total dose damage is important, but is adequate for many applications

Flash Memories Are Attractive for Certain Application

- Memory cells are not affected by upset
- Total dose degradation limits their use (typical failure below 10 krad)

Advanced Memory Technologies Are Evolving

- Ferroelectric technology